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A Further Contribution to the Study of the Phenomena of Interaction.

BY SIR ALMROTH E. WRIGHT, F.R.S.

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A FURTHER CONTRIBUTION TO THE STUDY OF THE
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*A further Contribution to the Study of the Phenomena
of Intertraction.*

By SIR ALMROTH E. WRIGHT, M.D., F.R.S.

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[PLATES 41, 42.]

Seeing that a phenomenon of lateral streaming which I recently described and put forward as convincing evidence of *horizontal intertraction* is construed otherwise by N. K. Adam,* I have, with a view to testing his interpretation of the phenomenon, made some further quite simple investigations. It will not be amiss, as a preliminary to detailing these, to place the real issue in debate—the issue as to whether there is such a *vis operans* as intertraction—before us in its proper perspective. I would propose to do this by recounting what led up to the investigation of intertraction.

The study of this *vis operans* began with observations on the effect of applying to furuncles requiring evacuation a plaster consisting of soap and sugar which is used in folk-medicine for “drawing” such boils. It was found that soap and sugar applied to open boils did, in point of fact, induce a copious welling up of lymph from the subjacent tissues. In pondering this effect it suggested itself that the sugar constituent of the plaster might be attracting, or to use the household word, “drawing,” fluid from the open lymph spaces; and that the soap constituent might be decalcifying and preventing the coagulation of the out-flowing lymph by staving off the sealing of the wound by scab.

Acting upon this idea—and, of course, mindful of the fact that Heidenhain had found that sodium chloride and other crystalline substances introduced into the blood call forth an increased lymph flow—I substituted sodium chloride for the sugar, and citrate of soda for the soap; and proceeded to treat

* ‘Roy. Soc. Proc.,’ A, vol. 113, p. 478 (1926).

wounds which required "drawing" with a 5 per cent. solution of sodium chloride combined with 0.5 per cent. of citrate of soda. This was found to be a very effective "drawing agent."

Later when I realised how voluminous was the outflow of lymph achieved, and recognised that this of itself would prevent the wound becoming lymph-bound, I omitted the citrate of soda, and employed as a "drawing agent," or if the term is preferred, as a "local lymphagogue," a simple hypertonic (2.5 to 5 per cent.) sodium chloride solution.

It is, I think, widely known that the simple hypertonic salt solution which had thus been arrived at was very extensively and effectively employed in the war in the treatment of those putrid lymph-bound conditions which result whenever surgical treatment of lacerated wounds is postponed.

Hand-in-hand with the therapeutic application of the hypertonic salt solution, its effect was studied both in the wards and in the laboratory. The ward experiments consisted in measuring the volume and the time relations of the induced lymph flow. In the case where scooped-out cavities in bone presented themselves, these were turned to use as collecting cisterns,* and where only flat superficial wounds were available artificial cisterns were made by strapping down upon the wound the upper ends of test tubes which had been cut across in the middle (we called these lymph-cups). In each case it was found that the filling-in of hypertonic salt solution into these cisterns produced an immediate in-draught of lymph, and that the in-draught diminished and finally stanchd as the salt solution became more and more attenuated. These happenings in the wound correspond, as we shall presently see, with those witnessed when hypertonic salt solutions are brought in contact with serum *in vitro*.

Concurrently with the aforesaid *in vivo* experiments, laboratory experiments were made to find out whether the (let us call it now) *tractor action* of salt solutions was exerted upon water as such, or upon albuminous solutions as such. The experiments in question (they are fully set out in the second edition of my Treatise on the Technique of the Teat and Capillary Tube†) brought out two things. The first was that when two receptacles which contain the one a strong salt solution, and the other water, are connected up in such a way that the water can pass, while the passage of salt is even by the lightest differential barrier impeded, then the level of the fluid gradually rises in the

* Fleming, 'Brit. Jour. Exper. Surgery,' vol. 7, p. 999 (1919).

† Wright and Colebrook, "Technique of the Teat and Capillary Tube," 2nd edition (1921), Constable, London, pp. 327-342.

receptacle which contains the salt solution. This shows that the salt, provided it be ever so lightly confined, can draw up water against the opposition of gravity. The second fact brought out was: that where, instead of water, an albuminous fluid and a confining barrier which is permeable to albumen are employed, there is obtained a much more rapid and voluminous in-draught of fluid into the salt solution.

It will be noted that in the experiments which have just been summarised, cognisance was taken only of tractor forces exerted by the salt solution.

As a next step in the study of the *vis operans*, steps were taken to render visible the movements which occur upon the frontier when a lighter albuminous fluid is imposed upon a heavier salt solution. And here, inasmuch as traction exerted in a particular direction by an element A upon an element B must have as its counterpart traction exerted in the opposite direction by the element B upon the element A, the experiments were so planned as to render manifest not only a down draught of the lighter albuminous fluid into the heavier salt solution, but also an updraught of the heavier salt solution into the lighter albuminous fluid. To this end, first the one, and then the other, of the solutions was artificially coloured. The experiments here in question are those which were described by me in my first communication on intertraction.* These were put forward as demonstrating the operations of intertraction, and they furnish what is, in my judgment, conclusive proof of the existence of such a *vis operans*. For ordinary convection movements are here definitely ruled out, and diffusion can furnish no explanation of the configuration I have called "*pseudopodial invagination*" or of the rapidity of the movements of interpenetration.

But none the less, in bringing forward the experiments in question as ocular demonstration of the operations of intertraction, I did not fail to point out that there are in the experiment (let us call it for the sake of brevity the experiment of vertical intertraction) superposed upon the effects of intertraction also effects of other derivation.

In the first place, we have here effects due to changes in specific gravity which affect the invading serum and salt solution respectively, after they have interpenetrated deeply. What would seem to happen is that the invading serum, becoming condensed by loss of water, becomes heavier than the "intracting" saline solution and so falls to the bottom of the vessel. And contrariwise,

* 'Roy. Soc. Proc.,' B, vol. 92, p. 118, figs. 1 and 2 (*a* and *b*) (1921). *Vide* also Plate 41, figs. 1 and 2 *infra*.

the invading saline solution having parted with some of its salt content, becomes lighter than the "intracting" serum, and so ascends to the surface.

Superadded to the gravitational movements just indicated, there is also a diffusion effect. Diffusion (co-operating with intertraction) finally brings about an equable dispersal of the salt and albumen and establishes uniformity between the subjacent and superjacent fluids.

These acknowledged (but I should have thought quite minor) blemishes in the vertical intertraction experiment have furnished Dr. Jessop* and Mr. N. K. Adam with the majority of the arguments by which they jointly, and the latter author also separately, have sought to make good that the phenomenon of "pseudopodial invagination" wherever obtained can be explained with any invoking of the concept of intertraction. With respect to that residue of arguments which those authors draw from their own experiments (I speak here only of those experiments which relate to salt and serum), these I must perforce (the reasons for this will appear later) ascribe to insufficiently thoughtful consideration.

To return to what is directly material to the subject matter in discussion, it was clearly of import for the general acceptance of intertraction as a *vis operativa* that an experiment should be devised which would display intertraction effects uncomplicated by effects due to alterations of specific gravity in the intertracting fluids. It was to this end that I planned the experiment (described and figured in 'Roy. Soc. Proc.,' A, vol. 124 (1926)), in which a paper disc impregnated with coloured serum and affixed to a cover-glass is floated face downwards upon the surface of a heavier salt solution. The radial streamers obtained in this experiment are essentially the same as those shown in Plate 42, fig. 7, *infra*.

This experiment also has been censured by Mr. N. K. Adam as non-probative—the gravamen of his criticism being that, just as in the experiment on vertical intertraction, so here, those parcels of the saline solution which come in contact with the albumen would by the disbursal of salt to it, become specifically lighter, with the result that they would ascend through the serum and be deflected by the under surface of the coverglass in such a way as to produce the horizontal streamers which come out radially from the margin of the filter paper.

With respect to the interpretation of the radial streamers I submit that it is inconceivable that rising currents, even if they started at separate foci, as Mr. Adam's theory would require, should, after passing through the texture

* 'Roy. Soc. Proc.,' A, vol. 108, p. 324 (1925).

of the filter paper, emerge from it in the form of discrete and sharply-outlined streamers. The very utmost that an upstreaming of salt solution (and it would be a general upstreaming) could be expected to effect would be an expulsion of coloured albumen in the configuration of a halo surrounding the disc.

Again *a priori* principles, and also direct inference from what is seen in the vertical intertraction experiment, combine to teach that ascending uncoloured streams of salt solution would be correlated with descending streams of coloured albumen. Now a distinctive feature of the experiment on horizontal intertraction in question is that there is here absolutely no visible downstreaming. Instead of that there can, under favourable circumstances, be discerned just within the periphery of the coloured paper disc a system of paler coloured centripetal striæ—striæ which would, of course, be the natural counterpart of the coloured centrifugal streamers.

But in point of fact, the issue as to whether the horizontal centrifugal streaming is produced by ascending currents impinging upon the filter paper disc is one which can very easily be set at rest by direct experiment. The following—for example—are elucidating experiments :—

(1) To begin with we can, instead of floating our albumen impregnated disc upon the surface of a heavier salt solution, take some three or four of such discs, lay them down one upon the other, dispose them between two glass slides, and then immerse the slides, after they have been firmly clamped together, into a vessel filled with saline solution. Here, in spite of the fact that ascending currents cannot come into operation, horizontal streamers exactly similar to those developed when the disc is afloat on the salt solution, come out from the periphery of the paper. (These are very delicate and difficult to photograph satisfactorily.)

(2) Again, we can, taking an albumen impregnated paper disc, paint its upper and lower surfaces except only the periphery with paraffin wax, and then set the disc afloat upon the saline solution. Here again, despite of upward currents being shut off, the familiar pattern of horizontal streamers is developed.

(3) Further, abandoning for the moment the paper disc, we can make a mixture of equal parts of coloured serum and of a 1 per cent. melted water agar, and then transfer a drop of this jelly to the surface of a slide upon either extremity on which we have placed thin slabs of glass as supports. We now bring down a covering slide upon our jelly in such a way as to flatten it out into a disc, and then we fill in all round it our saline solution. Here, again, despite the fact that no up-streaming currents can impinge upon the surface of the disc, horizontal streamers come out from its periphery (Plate 41, fig. 5).

(4) We take a square coverglass and paint paraffin wax upon its upper surface, leaving bare only a narrow strip along one edge. We then take a *very little* coloured serum, dispose it along the length of this ledge, and then float the coverglass, paraffined side uppermost, upon a 5, or, better, upon a 7·5 per cent. solution of salt, taking care in setting it afloat to bring down the margin that carries the serum last, and as gently as possible upon the salt solution. From the launching raft thus provided the serum is automatically drawn off by the salt solution, and is, as the photograph shows, now dispersed over the surface of the salt solution in the form of a palisade of horizontal streams (Plate 42, fig. 6). Here again it is clear—for the serum is reposing upon a ledge protected from below—that the horizontal streaming cannot be caused by any impact of ascending currents.

(5) Another also very simple experiment is the following—which was specially devised to dispose of Mr. Adam's general criticism that the water employed as a solvent for the salt will, as soon as it has been sufficiently lightened by the disbursal of its solute, ascend through the superincumbent serum. This potential source of fallacy will be removed if we substitute in our paper disc experiment for the solution of salt in water a solution of salt in serum. When having made that modification we set a serum impregnated disc afloat upon a salted serum, we bring out, just as in previous experiments, horizontal centrifugal streamers (Plate 42, fig. 7). Those now obtained differ, however, in two respects from those obtained with the watery saline solution. In the first place, they develop much more slowly; and again they are much less rapidly dispersed by diffusion. The slower development is no doubt correlated with the greater viscosity of the serum, and the slower dispersal with the fact that here diffusion is limited to a diffusion of salt out of one albuminous fluid into another sample of the same albuminous fluid, whereas where albumen is superposed upon a watery salt solution, three several elements—to wit, albumen, water and salt—are transporting themselves by diffusion the one into the other.

Reflexion having now placed at disposal for use in intertractional experiments a saline fluid which does not lie open to the imputation of being convertible into a fluid lighter than the superincumbent serum, the next thing that required doing was to substitute in the vertical intertraction experiment, as had just been done in the disc experiment, salted serum for the plain saline solution. For clearly there was now prospect of converting by this device that combined, intertractional, gravitational and diffusional experiment into one that should be purely intertractional.

A comparison of figs. 1 and 2 which are photographs of down-traction exerted by watery saline solution upon serum, and up-traction by serum upon watery salt solution, with figs. 3 and 4 which are photographs of down-traction exercised by salt serum upon serum and up-traction by serum upon salted serum, will show that the anticipation in question is in point of fact realised.

In figs. 1 and 2 we have intertraction complicated (we may deal with this first) by gravitational phenomena due to alterations which supervene in the down or up-going streamers as soon as these have invaginated themselves sufficiently deeply into the invaded fluids. The bulbous tips of the streamers are, doubtless, the results of downward and upward convectional movements occurring in the streamers when the invading fluid becomes, as the case may be, denser or lighter—the solid ends of the downward directed bulbs being perhaps comparable to what is seen when soap solution gravitates to the bottom of soap bubbles. Further all over the field, in figs. 1 and 2, we have conspicuous evidence of dispersion produced by diffusion.

In figs. 3 and 4, on the contrary, we have practically uncomplicated intertraction. That the disturbing influences of gravity and diffusion have been eliminated is seen in the undistorted shapes of both the down- and up-going streamers and in the definiteness of their outlines. Further—but this point is not brought to cognisance in the photographs—the invading streamers, in lieu of going rapidly to the bottom or, as the case may be, ascending rapidly to the surface, remain for a long time, as it were, suspended in mid-air. It is a case here of the tractor forces of the salted serum being impotent to draw the now salt satisfied, intracted serum any further down hill; and of the tractor action of the unsalted serum being impotent to draw the salt impoverished intracted serum any further up hill.

A few words may now be said upon the technique of bringing into view intertraction figures. Reflexion will show that in every case two conditions must be satisfied. The *first* is that all direct mechanical commingling of the fluids employed must be avoided. These must be disposed accurately the one on the one side, and the other on the other side, of a sharply-defined frontier. *Secondly*, when we want to witness intertraction movements across a particular frontier, we must arrange for the mechanical forces which oppose such transgressional movements to be less powerful than those that oppose intertraction along the frontier. In other words, we must, when minded to witness intertraction in the vertical plane take care that our intention is not defeated by our fluids intertracting horizontally. And similarly, when minded to witness

horizontal incursion we must put impediments in the way of vertical interpenetration.

Both these conditions are satisfied in all the experiments described above, and also in those which still await description. In the case where serum is imposed upon salt solution in a plane walled vertical cell, the required frontier is provided by the lighter serum taking up a position superficial to the heavier salt solution ; while the second requirement is satisfied by the fact that both fluids occupy the entire breadth of the cell, with the result that neither fluid can get round the flanks of the other to set up horizontal intertraction. In short, the circumstances are such that in the vertical intertraction experiment there is bound to be either vertical intertraction or none.

Again, in the experiment in which a serum impregnated paper disc is floated upon the surface of salt solution, the required frontier is obtained by the device of confining (that is the reason why we blot off all excess) our serum within the texture of the filter paper : Further in the same experiment the required obstacle to vertical intertraction is provided by our employing a salt solution of greater specific gravity than the serum. As soon as we grasp the principle that intertraction is bound to follow the line of least resistance, we appreciate why when we float an albumen impregnated disc on an appreciably heavier salt solution we are bound to get horizontal intertraction.

In the further experiments—that in which paper discs are clamped between two glass slides ; that in which we employ a disc or serum agar applied to an upper and a lower slide ; that in which we employ a paraffin-coated disc ; that where we place our serum upon the ledge of a cover glass ; and, lastly, that in which we impose our serum impregnated disc upon salted serum ; we again in each case establish a definite frontier between the serum and salt solution, and we employ also in each case a definite mechanical obstacle to block out vertical, and so compel horizontal, intertraction.

The following experiments further illustrate the principles formulated above :

Experiment 1.—We take two shallow glass vessels with vertical walls—such, for example, as the doublets which constitute a Petri dish—and we coat the inner face of the walls of the one dish with paraffin wax—leaving the walls of the other uncoated. We then, having filled into each dish a saturated salt solution three or four times diluted, draw up some coloured serum into a pipette, and transport a small quantum of this first to the one and then to the other dish—letting the serum in each case run down perfectly quietly from the vertical wall of the vessel on to the surface of the salt solution.

In the dish with unparaffined walls the serum will, as soon as it has run

down on to the salt solution, be thrust up against the wall by capillary attraction, and will consequently instead of running off into the centre of the vessel run round its periphery in the form of a coloured crescent. There will now all along the horns of this crescent be a display of vertical intertraction; but, in as much as capillary attraction is here pressing the serum up against the walls, there will be no horizontal intertraction. At the same time, if it so happens that the serum runs down from the wall into the salt solution more rapidly than it can be absorbed into the meniscus, there will in the sinus of the crescent come into view also horizontal intertraction. Here radial streamers will pass off from the walls.

In the vessel with paraffined walls—and the same will, of course, happen in any vessel which is filled brimful with salt solution—there will, for the reason that there will be here no thrusting up of serum against the walls, be no vertical intertraction contiguous to these. Instead of that the serum will flow off from the walls either in the form of diverging horizontal streamers, or, when an excess of serum has been employed, in the form of a superficial pellicle from which afterwards horizontal streamers will flow off in all directions. But here, also, vertical intertraction may come into view—descending streams coming off the under surface of any pellicle that has appreciable depth, and also from the under surface of any derivative streamers which may be heavy enough to indent the surface of the salt solution.

In summary, if we employ in these experiments only very minute quantities of serum there will come into view in the vessel with unparaffined walls only vertical, and in the vessel with paraffined walls only horizontal, intertraction. If, on the other hand, we employ somewhat larger quanta of serum there will be superadded, in the one case, to the vertical, horizontal, and, in the other case, to the horizontal, vertical intertraction.

Experiment 2.—We take, again, a vessel with vertical walls, and fill it, let us say, half full with our 4 to 5 times diluted saturated saline solution, and tilt it so that its walls may make on the upper side, an acute, and on the lower side an obtuse angle with the surface of the contained fluid. We now, taking up into a pipette two equal portions of coloured serum, let the one run down very gently from the upper, and the other in a similar manner from the lower wall upon the surface of the saline solution.

The first of these quanta will give only vertical intertraction—for here the circumstance that the free margin of the meniscus descends steeply to the surface of the salt solution constitutes an obstacle to horizontal intertraction.

The quantum of serum which has been expelled upon the lower wall of the

vessel will, on the contrary, in conformity with the fact that the free border of its meniscus slopes off very gradually into the general plane of the surface of the salt solution, give horizontal intertraction. This portion of serum will, of course, in addition to furnishing horizontal streamers from its free border, furnish also descending streamers from its inner margin which is applied to the walls of the vessel.

Experiment 3.—We roll out a pellet of plasticine into a very thin cylinder, flatten this out, and then lay down two strips of it transversely upon an ordinary microscopic slide, disposing them at such distance that the interval can be spanned by a coverglass. We now press a coverglass firmly down upon these supports until only a narrow chink is left between our glass surfaces. Into the cell thus formed we fill in a saline solution which is only just heavier than our coloured serum. Then—turning up our slide so that it shall lie in the vertical plane—we run in midway along the upper border of the coverglass a drop of our coloured serum. This will, of course, float upon the salt solution, but will hang down in it in the form of a plano-convex figure with its convexity downwards. The conditions will here be comparable to those which present themselves when dealing with superficial streamers which are heavy enough to indent the surface of the salt solution. Descending streamers will now come off from the under surface of the serum, and at the same time the serum will be carried out right and left in a thin line along the surface, until arrested by the lateral confines of the cell.

When, filling in the cell now with a somewhat lighter salt solution, we introduce a drop of serum midway along the lower border of the cover-glass, that drop, after first disposing itself in the form of a plano-convex figure with convexity uppermost, flattens itself down under the influence of gravity, disposing itself as a layer at the bottom of the cell. No sooner is this gravitational movement completed than intertraction phenomena begin to manifest themselves. Inasmuch as horizontal intertraction is barred by the fact that the serum cannot go any further right or left, we have here an upward streaming. Further, it may be noted that the upstreaming begins first in the median line of the cell, where the serum is still a little indented upwards—thus illustrating the general principle that eminently favourable conditions for the occurrence of intertraction are provided when the one fluid is lying in a sulcus provided by the other.

Experiment 4.—We get ready a shallow dish containing a fourfold diluted saturated salt solution, and then make an implanting spatula by taking a square coverglass and coating it with paraffin wax front and back, except for

a narrow strip left upon one side along one margin. We then take any kind of a rod to serve as a handle, and fix it with plasticine to the edge of the cover-glass which lies opposite to that upon which we have formed the implanting ledge. We now spread a small drop of coloured serum upon a microscopic slide; and having done so, charge our spatula by carrying it, with its ledge down-turned, along the face of that slide. Then, holding the cover-glass perpendicular and steadying our hand, we touch off the serum upon the surface of the salt solution and withdraw the spatula. This operation, if accurately carried out, gives us a narrow longitudinal implantation; and from this we obtain—inasmuch as our implantation has appreciable depth as well as length—uncomplicated vertical intertraction. It takes the form of a very picturesque palisade of descending streamers. If, on the other hand, our technique has been imperfect, and we have (*a*) either taken up too much serum upon our spatula, or (*b*) have dipped too deeply, or (*c*) have in implanting not held the coverglass absolutely perpendicular, we get in addition to vertical intertraction a certain amount of horizontal dispersion, and, again, from this there may be developed horizontal intertraction figures.

As a second procedure, we take as our spatula a coverglass of which one surface only has been coated with paraffin and the other moistened with water. We place a charge of coloured serum upon the moistened face of the cover-glass and then bring this down at an obtuse angle upon the surface of the salt solution. The serum will now, in conformity with the fact that we have formed a convex meniscus, stream off upon the salt solution in the form of a delicate pellicle, and this will, if we hold our hand perfectly steady, give intertraction figures such as are obtained with a launching raft.

We now, with a view to furnishing ourselves with a vertical receiving screen which we can set up in our salt solution, take a coverglass and set it upright in a pellet of plasticine—flattened out so as to provide a stand or foot.

When this has been put into position in the salt solution, we recharge the bare face of our coverglass with coloured serum, and, sloping this spatula as before, bring it down very gently upon the salt solution a little distance in front of our vertical receiving screen. The serum will now, as before, stream off upon the surface of the salt solution, will impinge upon the coverglass, will pack itself up against this, and will then descend along this obstacle in a palisade of streamers.

A final word now requires to be said in justification of the position taken up by me above with respect to Dr. Jessop and Mr. Adam's discountenancing of intertraction, and their impugning of its claim to rank as a *vis operans* which

brings about the commixture of certain pairs of fluids. I have ventured to say that all the arguments which were newly adduced in their paper were deductions from experiments which were insufficiently thought out.

The first in order of these arguments is Dr. Jessop and Mr. Adam's joint contention that no intertraction streamers appear when shallow pools of fluid are placed side by side upon a glass slide. Photographs 8 and 9 show that all that is required for the bringing into view intertraction figures, in the case of fluids disposed side by side in shallow pools, is to exercise care to prevent any preliminary commingling of the fluids.

The intertraction figures depicted in Photo. 8 were obtained by laying down four superposed narrow strips of filter paper transversely upon a microscopic slide, clamping down another slide firmly upon these, and then filling in on one side coloured serum, and then, as soon as a frontier had been established by the inhibition of the filter paper with serum, filling in the other cell with saline solution.

In the experiment depicted in Photograph 9 another quite simple device was employed. Here a non-tapering capillary tube was coated with paraffin, and then this was scraped off upon one side in such a way as to form a longitudinal groove. This done the paraffined capillary tube was inserted (with the longitudinal groove directed laterally) between two slides which were supported at their ends upon thin glass slabs. Communication between the two sides of the slide having been in this manner cut off, coloured serum was filled into one compartment, and salt solution into the other. And finally when the fluids were in position the capillary tube was rotated in such a manner as to bring the groove aforementioned into the vertical plane, and so open up a narrow channel of communication between the fluids. The opening of this tap is immediately followed by the development of horizontal streamers.

I pass now from the consideration of Dr. Jessop and Mr. Adam's experiment with shallow pools to Mr. Adam's experiments with albumen impregnated discs.

These have furnished three observations which he brings forward as discountenancing the theory of intertraction. The *first* is that when an albumen impregnated disc which is floating upon a heavier salt solution is tilted, the streamers instead of coming out all round, come out only from the upper edge of the disc. The *second* is that radial streamers fail to make their appearance when the disc is placed *in* (the italics are mine) a shallow pool of salt solution. The *third* is that when a disc soaked in coloured salt solution is floated upon a heavier albuminous solution "the colour is washed out in descending instead of in radial streamers."

To the animadversions founded upon the two first of these observations perfectly obvious replies can be given.

With regard to the *first*, it has been shown above that intertraction always follows the lines of least resistance. When, therefore, gravity is brought in operation differentially by tilting the disc it is only to be expected that upward streaming should (since it will be reinforced by gravity) continue (and be increased); and that downward streaming, since it would be opposed by gravity, should be suppressed.

With regard to the objection that horizontal streamers fail to appear when the albumen impregnated disc is immersed (for I take it that the descriptive term *in* denotes immersion), it will be plain that, for as much as the entire upturned face provides a much wider portal of outlet than the edge of this disc, and since up-traction through this face would be aided by gravity, it is to be expected that vertical should in the circumstances replace horizontal intertraction.

I come now to Mr. Adam's third animadversion—that founded upon the observation that a disc of filter paper soaked in coloured salt solution gives, when floated upon a heavier albuminous solution, descending instead of radial streamers. I had neglected to make this experiment, but have now verified Mr. Adam's finding.

Mr. Adam's point, however, has, as will be appreciated, lost all serious theoretical importance by its having been demonstrated above that intertraction is a *vera causa* of radial streaming.

There would, despite of that, be a blot upon the theory of intertraction, if a lighter salt solution floated upon a heavier albuminous solution did not give a radial streaming.

I therefore, going over in my mind the principles of the technique for obtaining intertraction figures as set out above, took counsel with myself after the following fashion: "It must be possible to obtain radial streamers from the salt solution impregnated disc, if by compressing the disc between two sheets of glass, I block all exit of salt solution from the upper and lower faces of the disc."

When this is done typical radial streamers are obtained, but the streamers are too delicate to give a satisfactory photograph.

"Again," so I reflected, "it should be possible to get horizontal intertraction figures by taking a slab of salted and coloured agar, and interposing this between two slides, and then surrounding it with an albuminous fluid."

Photograph 10 shows that we can in this manner obtain very good intertraction figures.

"Lastly," so I reasoned further, "the obtaining of radial streamers

from a disc of any lighter fluid, floated upon any heavier fluid, must depend upon there being between the fluids a difference of specific gravity which shall be sufficient to offer effective opposition to vertical intertraction."

Giving effect to this reflection I took a particular albuminous fluid upon which a disc soaked in 3 per cent. coloured salt solution had given notable downward streaming, and inspissated it by evaporating it down in an incubator to three-fourths of its original volume. When that had been done, and again a disc soaked in 3 per cent. coloured salt solution was superimposed, the tardily developed horizontal intertraction figures which are shown in Photograph 11 were obtained.

Further points with regard to the orientation of intertraction now suggested themselves. In the first place it became evident that, whether we float a disc impregnated with salt solution upon an albuminous fluid, or a disc impregnated with albuminous fluid upon salt solution, there is bound to be at one end of the scale a difference of specific gravity such as will give only horizontal intertraction, and at the other end of the scale a difference which will give only vertical intertraction, and somewhere in the middle of the scale a difference of specific gravity which will give either vertical and horizontal intertraction (the second supervening upon the first) or else diagonal intertraction. In point of fact all these orientations and varieties of intertraction can be obtained. For example when a disc soaked in 3 per cent. coloured salt solution was imposed, instead of upon the inspissated albuminous fluid before spoken of, upon the un inspissated fluid, there was developed, instead of purely horizontal intertraction, vertical intertraction, followed (after ten or more minutes when, no doubt, the hydrocele fluid had become denser by inflow of salt) by definite horizontal intertraction. And again while a disc of filter paper impregnated with human serum (the coloured human serum employed had a specific gravity corresponding to that of a 3 to 3.5 per cent. salt solution) was imposed upon a salt solution of 3 per cent. or over gives in every case only horizontal intertraction; such a disc imposed upon 2 per cent. salt solution gives vertical followed by horizontal intertraction; or according to circumstances "*diagonal intertraction*"—the streamers descending at an angle of perhaps 45° to the vertical, producing a figure very similar to that of a wicker hen coop.

Finally, the consideration of the facts just detailed suggests that in flotation experiments such as are here in question, factors other than differences in specific gravity may influence the results. It would seem probable—regarding for example the fact that 3 per cent. salt solution offers adequate resistance to the

downward streaming of serum from a filter paper disc—that the adhesion of the serum to the filter paper, and, in correlation with that, the closer or looser texture of the filter paper may, when the orientation of intertraction hangs in the balance, determine its direction. And in view of the fact that there is not an exact parallelism between the results obtained when a serum impregnated disc is floated upon salt solution, and those obtained when a salt impregnated disc is floated upon serum, it may perhaps be suggested that while a loosely textured filter paper may give a sufficiently close frontier for serum, a more closely textured filter paper may be required for salt solution.

In conclusion I beg to express my gratitude to Mr. R. M. Fry for valuable help in my experiments and for the photographs which illustrate this paper.

[*Postscript with additional figure (fig. 12) added March 9th, 1927.*—In the course of proof correction it suggested itself to me that a pattern of centripetal streamers would infallibly be developed if a crystallising dish or similar vessel was filled with saturated salt solution, and a meniscus of coloured serum was then run round its periphery. Further it suggested itself that if a cylindrical pillar was set up in the centre and was ringed round with coloured serum there would be obtained from the meniscus a pattern of centrifugal streaming. And finally, consideration indicated that a pattern of combined centripetal and centrifugal streaming would be obtained if there were placed upon the floor of the dish a glass ring (such a glass ring as is used for the construction of a live-cell), and saturated salt solution were then poured without and within nearly up to the top of the ring, and then coloured serum was painted on each side with a small camel's hair brush.

In all the three variants of the experiment here outlined singularly beautiful horizontal and perfectly regular intertraction figures are obtained:—the pink (eosin-coloured) centripetal streams in variants 1 and 3 of the experiment reminding one remotely of the Japanese flag; while the centrifugal streams obtained in variants 1 and 3 call to mind quite vividly the corona of tentacles coming off from the disc of a fully expanded sea-anemone.

The photograph (fig. 12) exhibits the pattern of combined centripetal and centrifugal horizontal intertraction obtained in the third variant of the experiment. It is inadequate in the respect that it does not bring out the fact that there is upon the walls of the central pillary also a little vertical intertraction.]



1



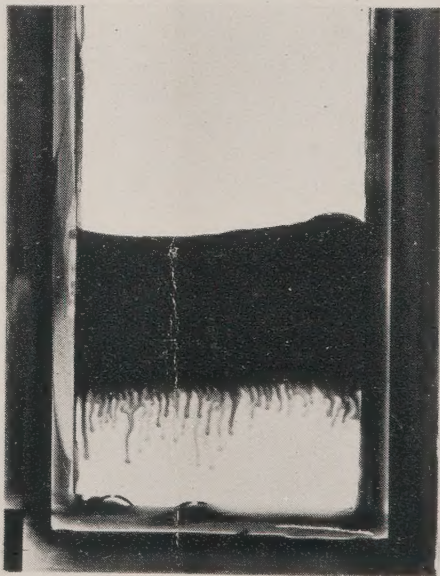
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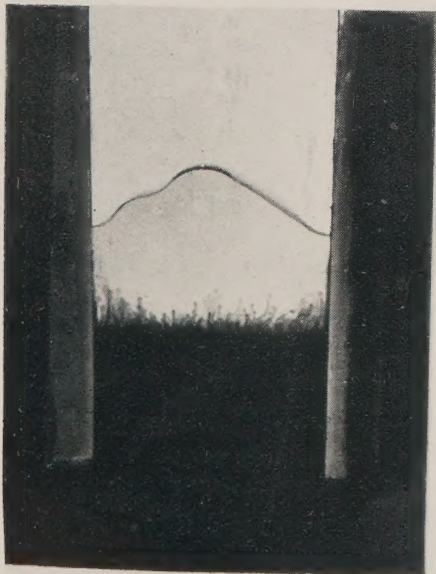
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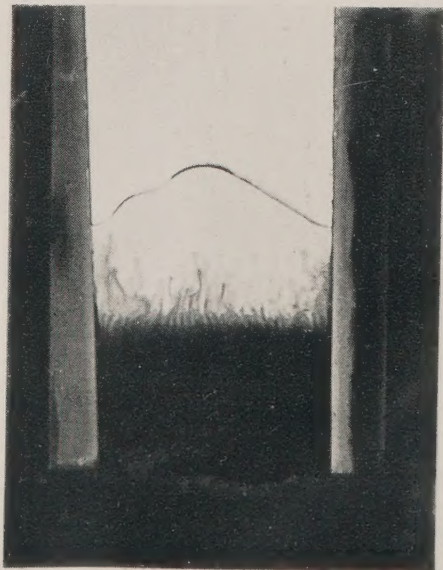
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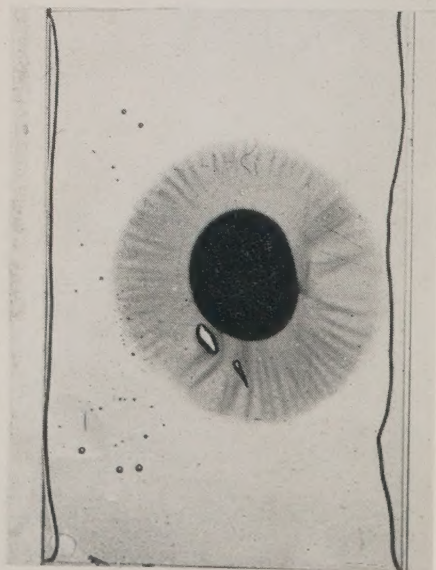
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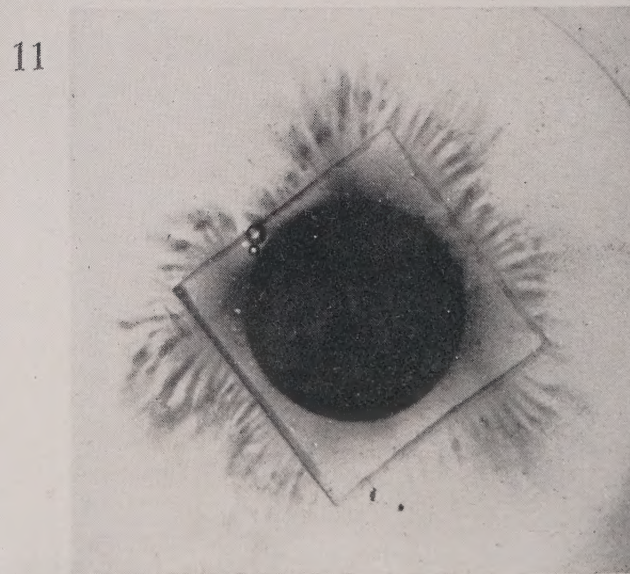
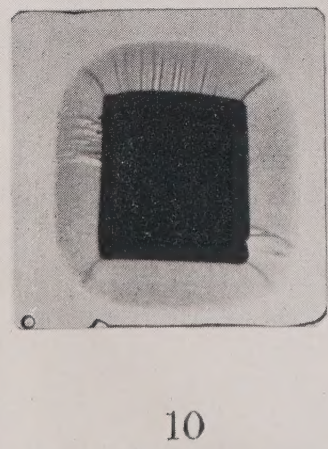
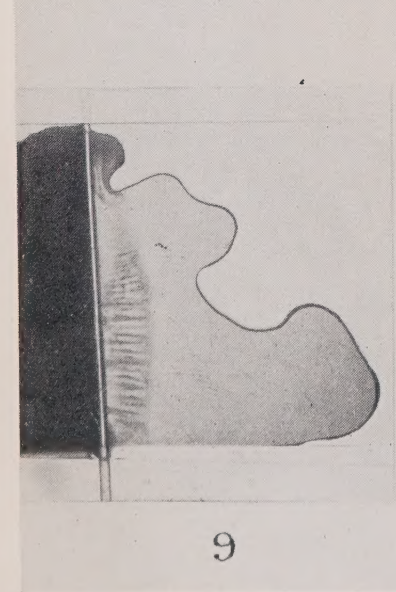
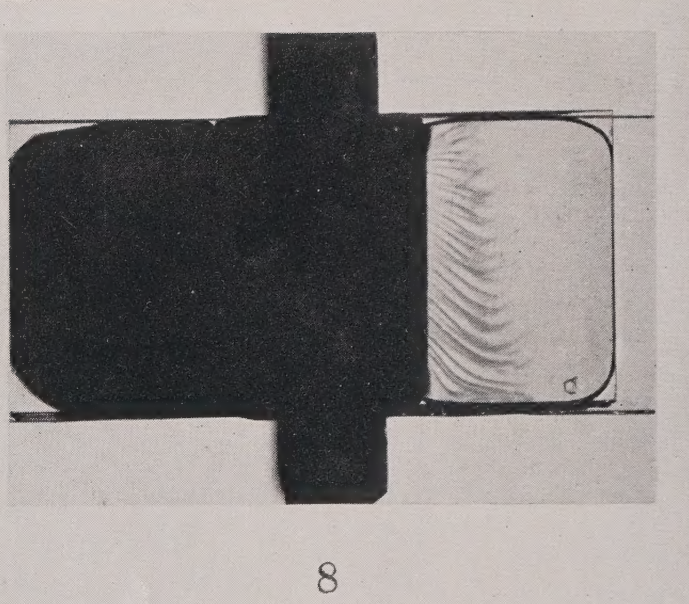
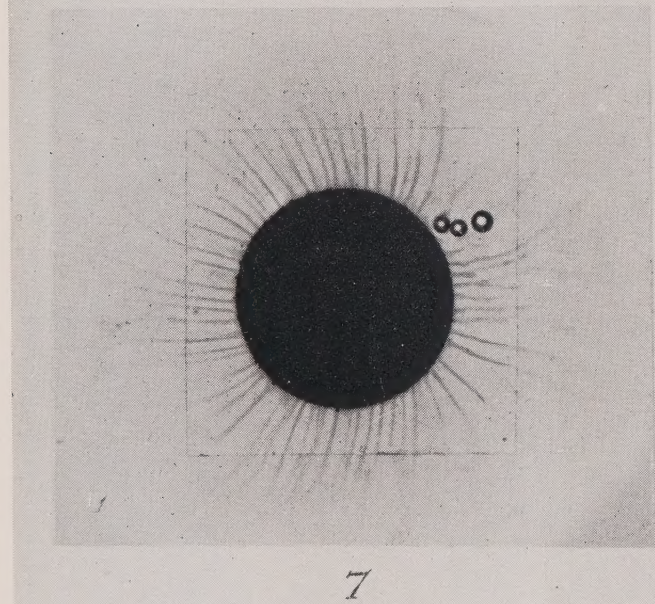
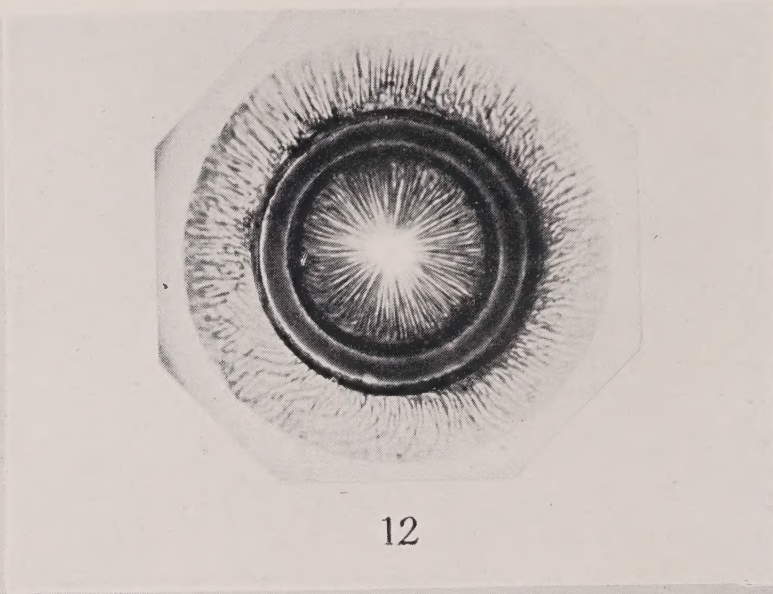
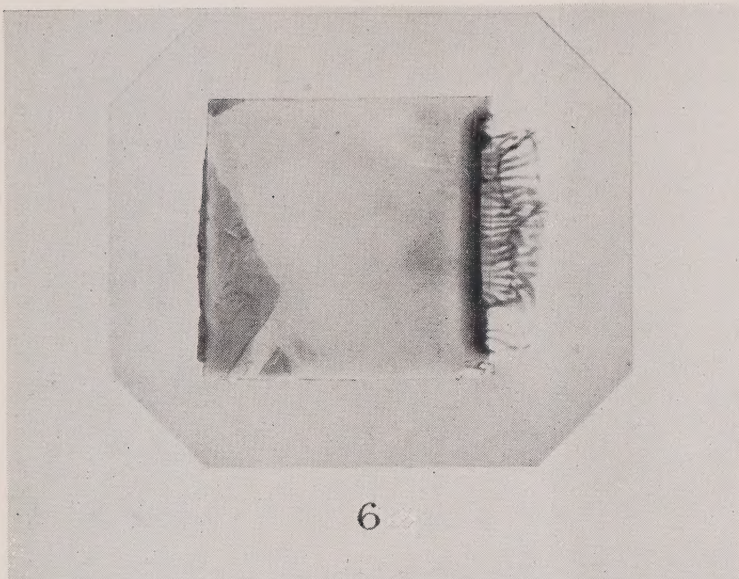
4a



4b



5



EXPLANATION OF PLATES.

PLATE 41.

- FIG. 1.—*Downward Traction*.—Coloured serum imposed upon uncoloured 5 per cent. salt solution.
- FIG. 2 (a) and (b).—*Upward Traction*.—Uncoloured serum imposed upon coloured 10 per cent. salt solution.
- FIG. 3 (a) and (b).—*Downward Traction*.—Coloured serum imposed upon uncoloured 2·5 per cent. salted serum.
- FIG. 4 (a) and (b).—*Upward Traction*.—Uncoloured serum imposed upon coloured 3 per cent. salted serum.
- FIG. 5.—*Horizontal Traction*.—A disc of agar impregnated with coloured serum has been interposed between two slides, and the cell thus made has been filled in with 5 per cent. salt solution.

PLATE 42.

- FIG. 6.—*Horizontal Traction*.—Coverglasses which have been coated with paraffin except for a bare ledge on the right-hand margin have been charged with coloured serum along this ledge, and have been set afloat upon 5 per cent. salt solution.
- FIG. 7.—*Horizontal Traction*.—A disc of filter paper which has been impregnated with coloured serum has been set afloat upon an uncoloured serum containing 5 per cent. of salt.
- FIG. 8.—*Horizontal Traction*.—A cell formed of two superposed slides has been divided into two compartments by clamping the slides together upon a number of superposed strips of filter paper. Coloured serum was now filled into the left-hand compartment, and when this had soaked into the filter paper barrier, uncoloured 5 per cent. salted serum into the right-hand compartment.
- FIG. 9.—*Horizontal Traction*.—The arrangement is the same as in fig. 8, except that here the cell was divided into two compartments by a capillary tube coated with paraffin except along a narrow longitudinal groove, which furnished a narrow channel of communication.
- FIG. 10.—*Horizontal Traction*.—Here a coloured slab of agar, which had a salt content equivalent to 2·5 per cent. salt solution, was interposed between two slides and was then surrounded by an uncoloured hydrocele fluid.
- FIG. 11.—*Horizontal Traction*.—A disc of filter paper soaked in 3 per cent. coloured salt solution was floated upon an uncoloured inspissated hydrocele fluid.
- FIG. 12.—*Horizontal Centrifugal and Centripetal Intertraction* proceeding from a twin meniscus disposed on either side of a glass ring standing in saturated salt solution.

